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The harvesting of the scallop Pecten maximus L. in France

Part II: Assessment and management of the Saint-Brieuc Bay population[1]

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After having been totally abandoned for some thirty years, the Saint-Brieuc Bay scallop fishery started up again on a modest scale in 1960. Within only a few years that fishery had become the largest in Europe, producing an average of nearly 10 000 tonnes of scallops every season. The extraordinary profitability of this activity soon caused the scallop fleet to balloon to an excessive size, and consequently it became necessary to establish an authority with extensive regulatory powers to administer the fishery.

ISTPM has developed a research program the ultimate aim of which is the rational management of the scallop population. The program is structured around three essential themes:

- study of the biological characteristics affecting the scallop population, such as growth, reproduction, and natural mortality;
- assessment of recruitment and prerecruitment;
- assessment of the harvesting effort and its impact on the population.

An understanding of these factors is essential if yearly quotas are to be rationally based on the available resources and if harvesting is to be managed in such a way as to yield maximum economic benefit.

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[1]Part I, "Introduction to the fishery", was published in the January 1978 issue of Science et Pêche (No. 276).

[2]ISTPM = Institut scientifique et technique des pêches maritimes (institute of marine fisheries science and technology).

The initial observations were made aboard the Roselys I in 1965 and 1966 (Faure, 1966). After an interval of some years, work resumed in 1974: monthly samples were taken with a view to studying the growth and reproduction of the target population, while observers went out aboard scallop draggers from Erquy in order to learn at first hand about the local harvesting techniques.

These procedures, however, quickly proved inadequate for the purposes of the research program. The ports are accessible only when tidal conditions are favourable, and this means that dragging time is limited to three or four hours per day. The boats are small, of ten tons or thereabouts and nine to ten metres in length, and consequently there is little room on board for scientists to engage in their activities. Furthermore, as most of the scallop beds have been intensively worked for some time, it was difficult to gather the requisite quantities of older specimens. Because of these constraints, and also because it was necessary to investigate spatial variations in recruitment, the Roselys II has been used since 1975.

Two series of scientific cruises are conducted each year. One of these takes place in summer, two or three months before the scallop harvesting season opens; its object is to estimate recruitment and prerecruitment and to carry out a number of trials with harvesting gear at various locations. The other data-gathering cruise series is conducted in February, a month or two before the end of the harvesting season. The purpose of this second series of observations is to assess the situation of the scallop population and to amplify and clarify the data obtained the previous summer. The conclusions based on the findings of these scientific missions are submitted to the regulatory body (Section V of CRUSCO), which sets the yearly quota and lays down the terms and conditions under which the next season's harvesting may proceed. These decisions are subsequently ratified by Marine Affairs.

Biology

The optimum productivity of a scallop population is determined by growth and yearly mortality rates, and data relating to reproduction should also be taken into account for the purposes of rational harvesting. We shall consider these several parameters in the following paragraphs.

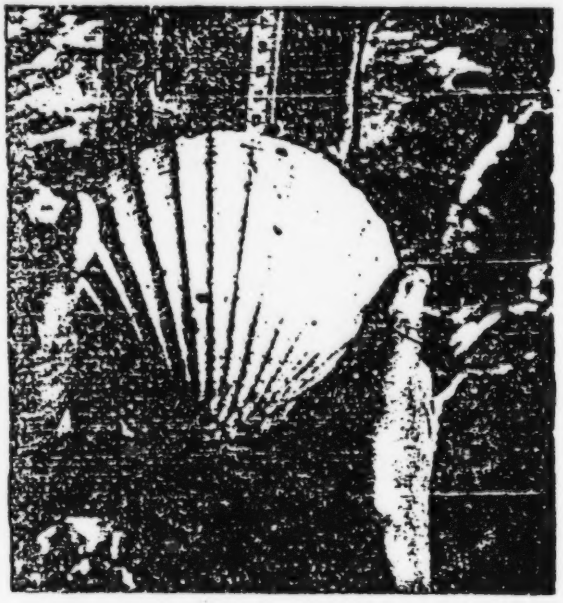

Fig. 1. Measuring a scallop with a ruler fitted with an end hook.

Growth

Analysis of growth in scallops is greatly facilitated by the presence of annual rings on the valves. By means of these, an individual specimen's age may readily be determined. Values are rounded off to the lower half centimetre, as measured along the dorsoventral axis with the hinge placed against the end hook of the ruler (see Fig. 1).[1]

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[1]This value is known as overall height, as distinguished from the width or greatest anteroposterior dimension, which is used as a reference in defining commercial size.

For each of the drag tows that constituted our reference matrix, we noted the size and age of every specimen caught. Average size at the time of the interruption in growth was determined by consolidating the values found in the course of all four winter cruise series (February 1975 to February 1978). This procedure yielded enough samples for the older age classes (5 years and over), which are sparsely represented as a result of the intensive harvesting to which the scallop beds of Saint-Brieuc Bay are subjected (see Table 1).

Age (years)	Overall height (mm)	Net weight (g)	Width (as measured in accordance with regulations) (mm)	Live weight (commercial) (g)
0.5	20			
1.5	65	38	70	46
2.5	87	96	99	111
C.S.	90	103	102	123
3.5	103	157	118	184
4.5	112	204	129	236
5.5	118	240	136	276
∞	133	349	153	395

Table 1. Mean growth of scallops in Saint-Brieuc Bay. Net weight: weight of washed and drained scallop. C.S.: commercial size.

Von Bertalanffy's equation fits the observed values remarkably well: the staircase-shaped profile (see Fig. 2A) takes into account the variations in the month-by-month growth rate that occur in the course of an annual cycle. The older the specimen, the more strongly marked the interruption in growth; this phenomenon is probably related to the dominance of reproductive activity.

Weight gain, for its part, may range from 10% to 30%, depending on whether the water and sediment inside the valves and the epibionts are included or whether clean scallops are considered. Aboard a scallop dragger, after every tow the scallops are sorted, hosed off, and stowed in bulk until they are placed in sacks in the course of the run back to port. Upon arrival, each batch is placed on pallets and weighed. This operation is performed an average of two to three hours after harvesting. An identical procedure was adopted for measurement purposes aboard the Roselys.

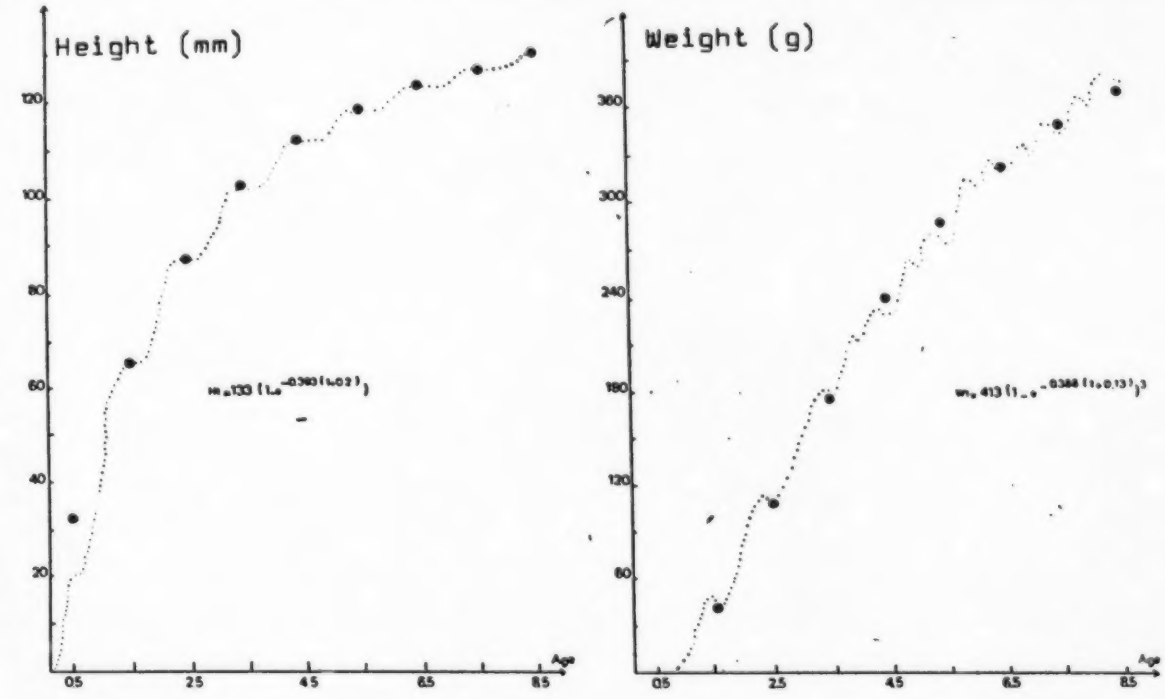

Fig. 2. (A) Increase in width, and (B) gain in weight of scallops in Saint-Brieuc Bay. The dotted lines represent the observed values, while the large black points represent the theoretical values deduced from the equations.

The mean values obtained in this way during the summer and winter scientific cruises were used as a basis for the construction of the weight gain curve (see Fig. 2B). Intermediate values were deduced from the data

gathered in the course of the monthly sampling operations carried out over the whole of 1974. Those data, reduced to mathematical expressions, are used in the management models developed below.

Reproduction

Samples of each age class were examined every month. The findings are shown in Fig. 5.

From October to January the gonad is flat, in a state of sexual quiescence, and the scallop is described as having no coral. In February the gonad begins to assume its characteristic colouring, namely milky white in the male part and orange at the distal end that produces the female gametes. Its size and weight increase very sharply in spring, reaching their maximum values in July and August. Gamete emission occurs in summer, when the temperature is in the 16°C to 18°C range. By September the gonad has been entirely emptied of its genital products; at this season it becomes turgescent and turns a uniform brownish colour.

This cycle is generally synchronized among the scallop populations of the bay. However, substantial variations were observed between offshore and inshore beds, and also between scallops of different ages: the first sexual maturity occurs at the age of two years, and older individuals were found to be mature earlier than those which were reproducing for the first time.

A scallop's reproductive potential increases with its size. In addition, the weight of the gonad increases more quickly than that of the adductor muscle: the ratio of gonad weight to adductor weight, which is of the order of 50% among two-year-old scallops, increases steadily thereafter until by the time the specimen is four years old the value stands at 80%.

Natural mortality

In order to determine the maximum productivity of the target population, a knowledge of natural mortality is indispensable. The indirect methods that are commonly used to estimate natural mortality from total mortality or mortality resulting from harvesting are inapplicable here in view of the absence of sufficiently accurate statistical series and also in view of the difficulty of conducting large-scale marking experiments.

Alverson and Carney (1975) have shown that there is a fairly close correlation between the maximum age observed in a population and the natural mortality rate. In the course of the Roselys's successive scientific cruises in Saint-Brieuc Bay in 1975 and the subsequent years, a considerable quantity of data on the age of the scallops inhabiting those waters was gathered (in all, over 60 000 determinations were made), and only a few dozen specimens were found to have attained or exceeded an age of 9 or 10 years. As some of our experimental drag tows were performed in areas that are harvested only rarely or not at all, it is highly probable that these values represent the age limit for the population. This being the case, it appears from the equations developed by Alverson and Carney that the corresponding natural mortality rate would be between 18% and 22% per year.

These values are fairly close to the values found by direct methods in the case of some scallop beds in British waters which had not been subjected to harvesting. Baird (1966) concluded that mean natural mortality was 26%, while according to Gruffydd (1974) natural mortality increases regularly after the age of five years, from approximately 15% at that age to 20% at the age of ten and rapidly thereafter.

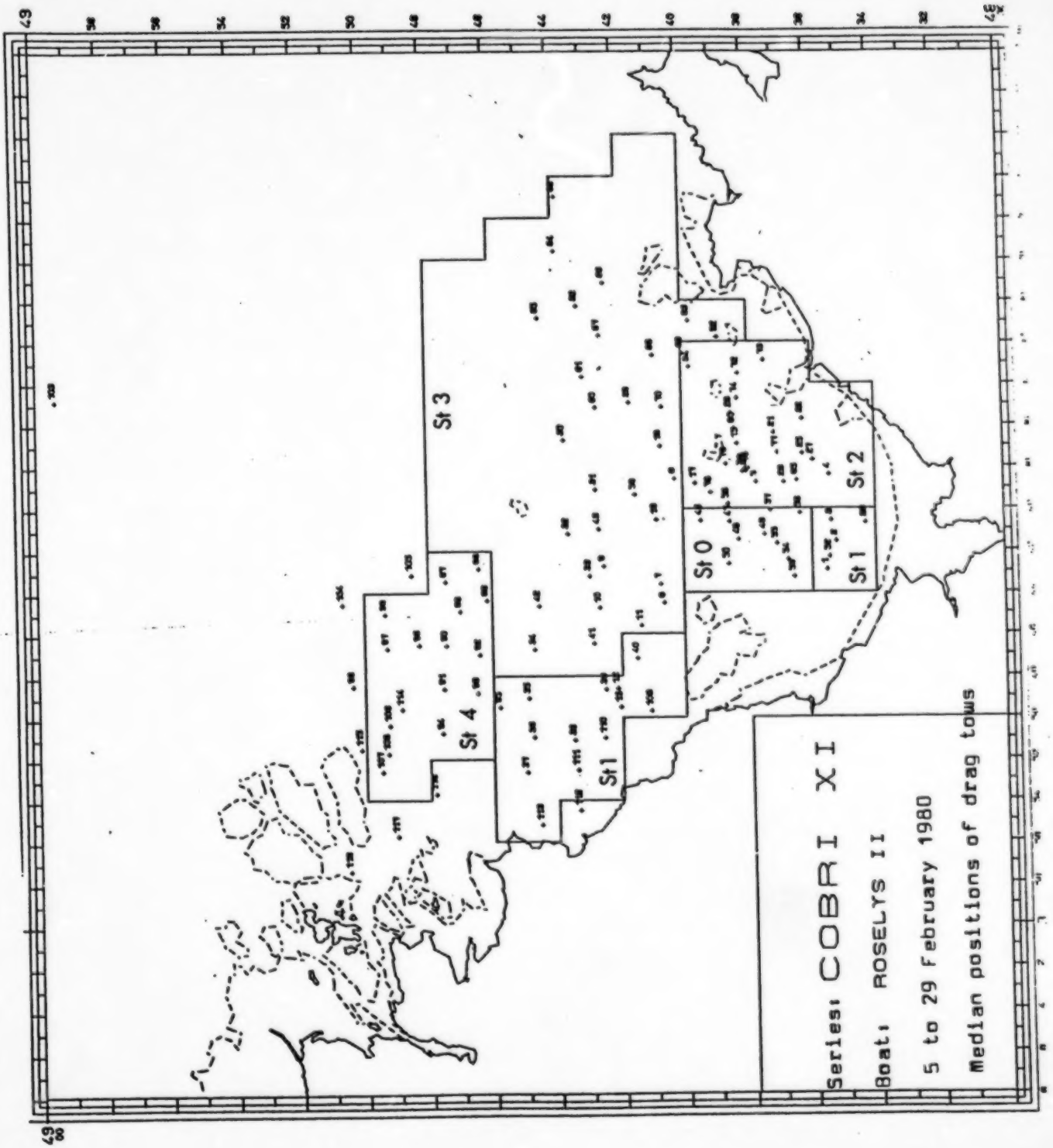

Fig. 3. Median positions of drag tows performed in February 1980 in the course of the data-gathering cruise series designated COBRI XI, and stratification.

Estimation of the scallop population of Saint-Brieuc Bay

The initial protocol had called for 25 drag tows of approximately 0.8 mile, distributed over the entire area of the bay. However, in view of the progressive extension of the fishery to the northwest and northeast, we decided to enlarge this reference matrix. The chart shown in Fig. 3 indicates, by way of illustration, the positions of the tows performed in February 1980 in the course of the data-gathering cruise series designated Cobri XI.

Two drags, each of which was two metres wide and fitted with a depressor plate, were used simultaneously. One of these was of what is known as the standard type. It featured two half blades, each bearing 10 teeth 100 mm to 130 mm in length, and the belly of the bag consisted of a fabric of linked metal rings 72 mm in diameter; the back of the bag had originally consisted of 35-mm mesh nylon netting, but this had been replaced with metal ring fabric in 1979. The other drag was of what is known as the fine-mesh type. Each of its two half blades carried fifteen 130-mm teeth, and the metal rings of the bag were only 50 mm in diameter. A drag of this type is a useful aid to estimating the abundance of one- and two-year-old scallops.

As an initial step, all findings were adjusted to a one-mile dragging distance. Next, in order to reduce the incidence of large variations in density between different sectors, the bay was divided into strata; this method is aimed at improving the accuracy of calculated abundance values. The stratification operation (see Fig. 3) took into account the nature of the ground, scallop density and demographic structure. The areas of the several strata were as follows:

Stratum 0, Caffa sector: 37 km^2
Stratum 1, western part of bay: 73 km^2
Stratum 2, eastern part of bay: 91 km^2
Stratum 3, offshore region: 348 km^2
Stratum 4, northwestern region: 90 km^2

The mean density (d_i) was calculated for each demographic class and for each of the strata. The next step was to calculate the mean indices of abundance for the various classes, and this involved the respective areas of the strata.

$$D = 1/A \sum a_i \cdot d_i$$

in which D is the final index of abundance,

A is the total (useful) area of the bed, 640 km^2,

a_i is the area of each stratum,

and d_i is the index of abundance over each stratum.

The weighted indices of abundance calculated for the whole of Saint-Brieuc Bay since 1975 are shown in Table 2. The most striking feature is the great variability in the size of a particular age group found in the course of successive data-gathering cruise series: the abundance of a good cohort (1973) is greater than that of a poor one (1977) by a factor of more than 20. Such fluctuations in recruitment, which are related to the vulnerability of the larval stages, have major implications for the question of what strategy should be adopted in the matter of stock management. The indices of abundance obtained from our data also constitute a means of determining the incidence of mortality among the population.

Mortality

The total mortality coefficient (Z) was deduced from the mean survival rate (S) among the members of the classes that had been subjected to harvesting between one data-gathering cruise series and the next: $Zt = \log S$. In order to avoid overestimating the survival rate as a result of the selectivity of the drags, which affected some of the specimens in group 2, only scallops three years of age or older were considered. Since 1975, the yearly survival rate

has fluctuated between 0.35 and 0.64, with a mean value of 0.54; this corresponds to a value of 0.62 for Z.

The coefficient of mortality as a result of harvesting, F, can be deduced from the equation $Z = F + M$. Assuming a natural mortality rate of 0.2, we find that the mean value of F is 0.42. Inasmuch as the value of F fluctuates from year to year, depending on the harvesting effort, it will be more useful to define the probability of capture per unit effort (q), which is nearly constant in view of the fact that harvesting techniques and the characteristics of the boats involved do not change much, owing to the system of regulation that is in effect. Applying the equation used by Gulland (1969), namely $F = q f$, in which f represents the harvesting effort, i.e. an average of 26 500 hours per season since 1975, we find that the value of q is equal to 1.6×10^{-5}.

Estimate of the exploitable biomass

For every scallop harvesting season since 1970, we know the total catch C and the harvesting effort f (see Table 3). As weight gain is negligible during the harvesting season, it is possible to determine <u>a posteriori</u> the exploitable biomass B at the beginning of each season by means of the following equation:

$$B = C/E(1 - e3^{-Z}$$

in which B is the exploitable biomass,
C is the total catch,
$Z = q f + M$
and $E = q f/Z$.

The biomass values estimated by this method (see Table 3 and Fig. 4) fluctuate by a factor of 1 to 3 between the poor years 1971/1972 and 1981/1982 and the exceptionally good year 1975/1976. However, there are a number of factors that should be taken into account:

- f and C are estimated values, and consequently the accuracy of this information declines with increasing distance backward in time;
- we are concerned with exploitable biomass rather than total biomass, and the proportion of 2.5-year-old scallops that have reached commercial size may be as low as 30% in some years and as high as 80% in others.

Series / Age group	1102 Sept 75	1104 Sept 76	1106 July 76	1108 Aug 78	1110 Sept 79*	1112 Sept 80*	1113 Sept 81*
1	1.1	1.3	5.5	0.2	5.0	5.0	0.4
					36*	37*	25*
2	357	10	14	260	3	87	28
					12*	107*	116*
3	41	286	10	46	114	8	50
4	14	36	112	78	55	92	64
Survival group 3 and over		0.65	0.35	0.64	0.44	0.54	0.64

Table 2. Indices of abundance calculated on the basis of the experimental data obtained from the research cruises conducted aboard the Roselys (*: indices calculated from data obtained using the fine-mesh drag with rings 50 mm in diameter).

Z = F + M
F: mortality as a result of harvesting
M: natural mortality
Z: total mortality

Harvesting season	Catch (C) (tonnes)	Harvesting effort (f) (hours)	Average catch/ unit effort (kg/hour)	Z	E	Exploitable biomass (tonnes)
1970/1971	7 650	40 500	185	0.85	0.76	17 600
1972	6 330	45 000	141	0.92	0.78	13 500
1973	12 500	44 000	284	0.90	0.78	27 100
1974	10 000	42 000	238	0.87	0.77	22 300
1975	8 500	40 500	210	0.85	0.76	19 600
1976	10 500	22 000	477	0.55	0.64	39 000
1977	9 500	29 000	327	0.66	0.70	28 200
1978	7 500	40 000	187	0.84	0.76	17 300
1979	6 740	26 000	259	0.62	0.67	21 800
1980	4 739	20 523	231	0.53	0.62	16 600
1981	4 040	22 800	177	0.56	0.65	14 400
1982	3 964	25 443	156	0.61	0.66	13 000

Table 3. Changes in catch size, harvesting effort and exploitable biomass, 1970 to 1982 (Z: total mortality; E = q f/Z; q: probability of capture per unit effort; f: harvesting effort).

	Jan.	July.	Jan.	July	Jan.	July	Jan.	July	Jan.	July	Jan.
Age	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5
Live weight	11	95	346	514	691	811	888	949	920	930	883
Weight, muscle	1.3	9.5	36	69	80	90	113	115	122	113	114
Weight, gonad	0	0	0	3.8	9.2	55	12.3	80	14	71	13
Edible weight	1.3	9.5	36	107	89.2	154	125.3	195	136	184	127

Table 4. Changes in weight in a cohort of 10 000 specimens, reference period January and July (weight values are expressed in kg).

It is important to bear the trend in mind: since 1977, the scallop population has been smaller than it was between 1970 and 1980, when its mean size was 27 300 tonnes. This situation is the result of the poor recruitment that has been observable since the exceptionally high reproduction of the summer of 1973. The situation would have been even worse had it not been for the fact that since 1975 a number of restrictions have been put into effect with a view to reducing the harvesting effort.

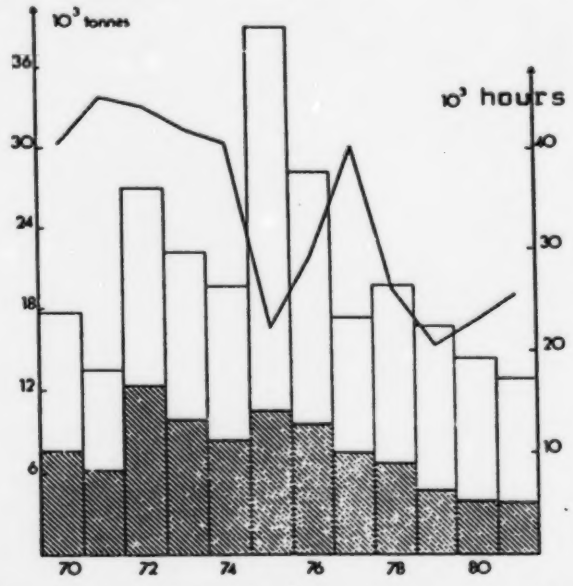

Fig. 4. Changes in biomass, harvesting effort (broken line) and catch size (shaded area) from the 1970-1971 harvesting season to the 1980-1981 harvesting season.

Optimum harvesting conditions

Maximum yield per cohort

If we monitor a cohort of 10 000 four-month-old juveniles that is not subjected to harvesting pressure, we find, applying a natural mortality (M) coefficient of 0.2, that the biomass (see Fig. 5) increases strongly during the first three years and reaches a maximum of 950 kg in the course of the fourth year, declining progressively thereafter (see Table 4).

Maximum production of edible parts (muscle and gonad) is attained in the fourth year, although marked seasonal fluctuations do occur because of changes in reproduction rates. Given the yearly coral development cycle, the best yields are obtained in the spring. From a biological standpoint, the ideal approach to harvesting would be to take all the scallops during the spring of their fourth year, especially in view of the fact that by then they would already have reproduced twice. This, however, would require the deployment of a very substantial harvesting effort, so that the operation would not be economically viable. In addition, such an approach would tend to amplify the saw-toothed pattern of fluctuation in catch size that results from the very wide range of variation in recruitment.

Commercial size and optimum harvesting effort

It thus appears that the most satisfactory practical solution involves striking a balance between yield per cohort and the harvesting effort required to obtain that yield. The mathematical model developed by Beverton and Holt (1957) offers a useful approach to the issue, as it affords a means of determining optimal harvesting conditions for a given population in terms both of commercial size (initial catching age) and of mortality resulting from harvesting (harvesting effort). Our findings relating to growth and mortality were integrated into the model, which was then used to describe equal production curves for a cohort of 100 million spat, a figure typical of an average situation in Saint-Brieuc Bay (see Fig. 6).

At the present time, the commercial size of scallops is 10.2 cm, corresponding to an initial catching age (tc) of 2.5 years. With this minimum commercial size limit, no more than 7500 tonnes per cohort, at most, can be harvested from the scallop population of Saint-Brieuc Bay (and to arrive at even that figure it is necessary to use a value of between 0.4 and 0.5 for the

rate of mortality resulting from harvesting). To obtain that yield, between 19 000 and 24 000 hours of dragging are required each harvesting season. With the same harvesting effort, it would in theory be possible to obtain a yield of 8500 tonnes, provided the initial catching age was increased by one year (i.e. provided the commercial size was set at 11.5 cm). In point of fact, it is difficult to quantify the potential increase. While it is true that dragging causes only slight mortality among one-year-old scallops, the impact on older specimens is much heavier. Observations have been made locally, but the findings cannot be extended to the fishery as a whole in view of its heterogeneous nature.

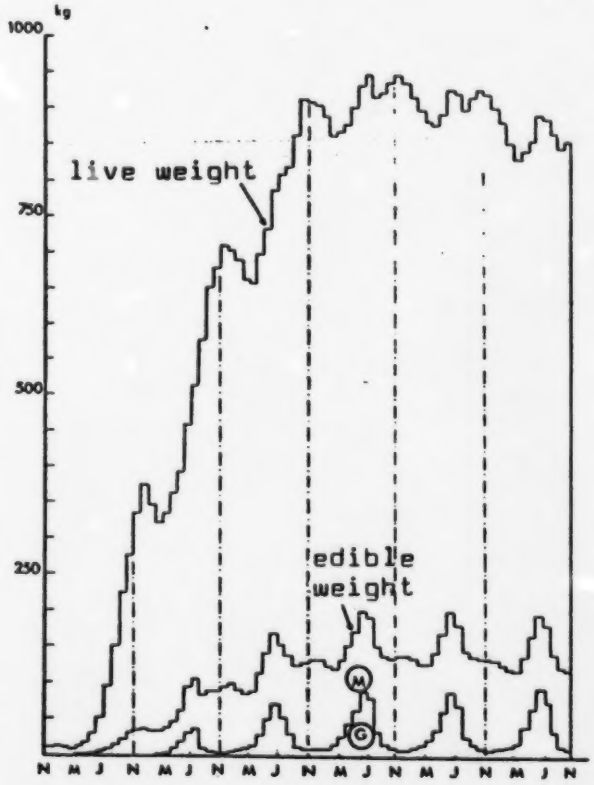

Fig. 5. Changes in biomass in a cohort of 10 000 individuals (four-month-old recruits) subjected to a 20% yearly mortality rate (M: muscle; G: gonad).

This restriction on harvestability was, in fact, applied in 1981-1981 and again, to an even greater extent, in 1981-1982, because of the small size of 2.5-year-old scallops in those seasons: the proportion of undersized specimens ranged from 50% to 100%, depending on the harvesting area.

Initial harvesting conditions

When the Saint-Brieuc Bay scallop fishery started up again early in the 1960s, harvesting was carried out within the framework of the general regulations, i.e. harvesting was prohibited during the summer, between 15 May and 30 September, and it was not lawful to land scallops measuring under 10 cm. During those early years yields were good, and the scallop fleet increased steadily in size: by 1975 nearly 450 boats were working the scallop beds of the bay.

Market demand, however, was growing much more slowly, and this situation led the local committees of the Saint-Brieuc Bay maritime districts to ask the Trades Committee on Crustaceans and Mollusks to adopt additional restrictions with a view to reducing the quantities of scallops that could not be sold. In the 1960s limitations were placed on dragging time, and in the subsequent years the harvesting season was made progressively shorter, until finally scallops could lawfully be harvested only from November to April.

Fresh restrictions were applied early in the 1970s: every operator was required to obtain a harvesting licence, and limitations were placed on the tonnage and power of the boats, 200 H.P. engines being the largest allowed. These regulations have proved effective: they served to keep the harvesting effort nearly constant between 1970 and 1975 (at 40 000 to 45 000 hours of dragging), even though the number of boats nearly doubled during that same period. As an illustration of how the system works, during the 1973-1974 season harvesting was permitted between 5 November and 18 April from Monday

to Thursday inclusive, for one hour and 30 minutes of actual dragging time per day. The scallop fleet operating in Saint-Brieuc Bay that season consisted of 380 boats, and the total landed catch amounted to 10 000 tonnes (Dupouy, 1974).

Improvements to date: management by quota

The first data-gathering cruises in the "Cobri" series (February and June 1975) revealed that while the 1973 year class was exceptionally abundant, the 1974 year class was practically nonexistent. Armed with this information, we could foresee that the 1975-1976 catch would break all records, assuming that the harvesting effort was maintained at the same level as in the previous seasons, but that as of the next year catches would collapse to the point where some operators would probably have to go out of business.

ISTPM therefore suggested a quota of 8000 tonnes, a figure which it was felt would ensure stable production during the two following harvesting seasons. To hold the catch down to this level, the harvesting effort was reduced by half in 1975-1976 and distributed month by month. The quota was actually exceeded, owing in part to monitoring problems at landing points, but the principle was maintained.

The quota system has now won acceptance within the industry, since it affords a means of organizing the market more effectively and hence of obtaining better prices. Since 1978, furthermore, closer surveillance at sea and the institution of official auctions ashore have considerably enhanced the effectiveness of this management approach. In the years since 1975, then, the harvesting effort has been modulated in accordance with recruitment abundance; it ranges between 20 000 hours and 40 000 hours per season, with an average of 26 500 hours (i.e. $F = 0.42$), as against an average of 43 000 hours (i.e. $F = 0.90$) from 1970 to 1975.

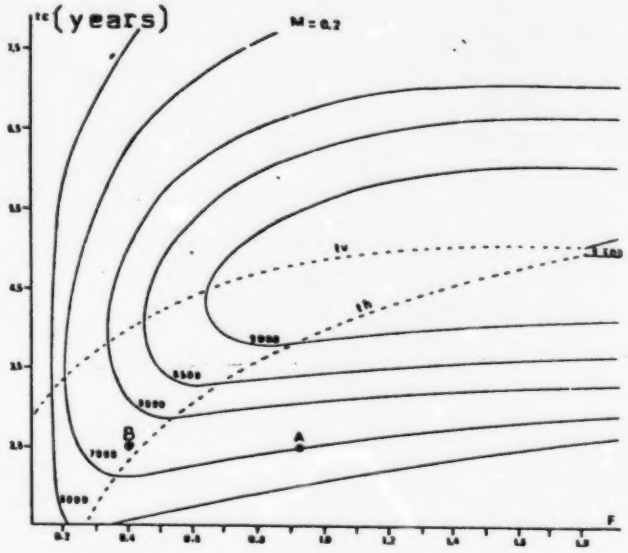

Fig. 6. Equal production curves (in tonnes) for a cohort of 100 million spat based on initial catching age (tc) and mortality resulting from harvesting (F). Optimum harvesting age for a given harvesting effort is indicated by the upper dotted line (tv), and optimum effort for a given commercial size is indicated by the lower dotted line (th). (A) represents the situation of the Saint-Brieuc Bay fishery between 1970 and 1975, and (B) represents the situation during the 1975-1981 period.

With respect to production, the result was an increase that can be estimated, from the diagram shown in Fig. 6, at 7%, while in economic terms the profitability situation of the fishery was considerably improved in view of the fact that this gain in production was achieved with a fishing effort that had been reduced by a matter of 40%. Furthermore, the value of the catch was greatly enhanced owing to the increase in average scallop size that resulted from the reduced harvesting effort. The average price per kg has more than tripled since 1974, and in constant franc terms this represents a real increase of over 50%.

There are other possible improvements. For example, management by quota has now brought the harvesting effort to somewhere close to its optimum level

for the minimum commercial size limit currently in effect (see Fig. 6). By raising the initial catching age from 2.5 years to 3.5 years, it would in theory be possible to obtain a further 15% increase in production while maintaining the harvesting effort in the 20 000 to 25 000 hour range. In the absence of adequate data on the mortality caused by dragging among undersized scallops, the effective impact of such a change is hard to quantify. This difficulty could be avoided in part by means of the adoption of a rotation system of harvesting.

Conclusion and outlook

The population dynamics studies that have been conducted since 1974 on the scallop beds of Saint-Brieuc Bay have yielded a substantial measure of understanding of the population and the changes that occur in it.

From a biological standpoint, a number of relatively stable characteristics of that population have been identified: increase in size, weight gain, age of first sexual maturity, reproductive cycle and natural mortality. However, recruitment continues to be subject to wide fluctuations. Seaborne research cruises afford a means of estimating cohort size a year or two before the specimens in question have grown to harvestable size, and this information can be used in setting quotas that are meaningfully related to fluctuations in the size of the population. The quota system that was established in 1975 was accompanied by a substantial reduction in the harvesting effort. It has resulted in better management of the scallop population.

The fact remains that since the exceptionally high reproduction rate that was observed in 1973, recruitment has fallen to a level that is abnormally low by comparison with previous years, and despite the management actions that have been taken, the population is having difficulty maintaining its numbers. Since

1979 the quota has been set at less than 5000 tonnes, and unless the recruitment situation shows signs of improvement in the near future, the Saint-Brieuc Bay scallop fishery may well begin to decline. Other types of fishing activity in the bay are also falling off: landings of Venus clams, which amounted to nearly 1000 tonnes in 1971, are now down to less than 200 tonnes yearly, sea urchin harvesting is only a memory, catches of crustaceans, king crabs in particular, are dwindling year by year as the population is harvested progressively earlier by other fleets (from Morlaix and Saint-Malo), and cuttlefish harvesting is dependent on annual recruitment and hence is highly unpredictable. Trawling alone is still holding its own, but the boats of Saint-Brieuc Bay are not powerful enough to be usable for that form of activity.

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